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TECHNICAL REPORT

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RESEARCH STUDY TO OBTAIN DATA PERTAINING TO THE OPTIMUM REQUIREMENT FOR DEHYDRATION AND REHYDRATION OF CERTAIN FREEZE-DRIED FRUITS AND VEGETABLES

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Menlo Park, California 94025

Contract No. DAAG 17-70-C-0187

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UNITED STATES ARMY
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FOREWORD

Problems are encountered in the rehydration and textural qualities of certain dehydrated and freeze dried fruits and vegetables such as lima beans, strawberries, peaches, pears and apricots. The lack of data pertaining to the optimum requirement for dehydration as well as rehydration of such products is one of the critical factors affecting their quality.

This report presents the result of investigation on the effect of variety and maturity as well as processing variables such as drying temperature, tray loading, additives, particle size, freezing temperature, chamber pressure and air velocity on the quality of freeze dried fruits and air dried lima beans.

Mr. Thomas R. Parks was the Principal Investigator and Mr. Samson T. Hsia and Mr. Joel Sidel the co-investigators in the research work for Stanford Research Institute. The U.S. Army Natick Laboratories Project Officer was Dr. Abdul R. Rahman of Plant Products Division and the Alternate Project Officer was Mr. Glenn Schafer of Plant Products Division, Food Laboratory. The work was conducted under Project No. 728012.12, Production Engineering.

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ABSTRACT

The relative effects of process and raw material variables on final product quality were determined for feeeze-dried strawberries, pears, peaches and apricots, and air-dried lima beans. Raw material variables studied were variety and maturity. Process variables included drying temperature, tray loading, additives and particle size. Variables involving freezing temperature, chamber pressure and air velocity were included as applicable. Following drying, samples were packed in a nitrogen atmosphere and placed in accelerated storage (100°F) for 6 months.

Varietal selection, stage of maturity and particle size were significant factors affecting the quality of freeze-dried fruits and air-dried lima beans. Except for strawberries, blanching was found necessary to ensure good appearance and proper rehydration as well as enzyme inactivation in the freeze drying of pears, apricots and peaches. Chemical additives did not improve either texture or flavor of rehydrated products.

INTRODUCTION

Freeze-Drying of Fruits

Freeze-drying as a means of food preservation has been known for many years. The ability to produce various high quality dehydrated foods by freeze-drying has been well documented in the literature. With proper rehydration, freeze-dried foods retain many of the physical and sensory characteristics of fresh and frozen foods. However, the relative high processing cost compared with other, more conventional methods of food preservation has largely restricted the application of freeze-drying to high priced food items such as meat, seafood, poultry, mushrooms, coffee, and prepared convenience foods, and has prevented its use on fruits and other low cost food items. Consequently, only a limited amount of information is available on the freeze-drying of fruits.

Recently, a few freeze-dried fruits have become commercially available in camping and back-packing supply stores or as candied fruits in specialty shops (Hirshberg, 1971). The major portion of freeze-dried foods produced in the United States is packed under contract to the U.S. Armed Forces. Because of their long shelf life, high degree of acceptance, and light weight, freeze-dried foods have become basic components of many combat and field rations.

The objective of this part of the study was to provide information on the effects of selected raw material and processing variables pertaining to the optimum conditions for freeze-drying of fruits. Four types of fruits were investigated in this study: pears, strawberries, apricots, and peaches. The raw material and processing variables studied included variety, stage of maturity, additives (when applicable), freezing rate, tray loading, platen temperature, and chamber pressure. The fruits were processed and freeze-dried under the various designated conditions, packaged under nitrogen in hermetically sealed containers, stored six months at 100°F, and sensory tested after rehydration.

Air-Drying of Lima Beans

Lima Beans and other similar legumes are seldomly dehydrated by artificial methods. Commercially, lima beans are available either as field-dried beans, which may be processed into canned products, or as frozen beans. Processes such as those for quick cooking beans as developed by Rockland et al., (1967) and Brown et al., (1968) used beans that had been previously field-dried then rehydrated. Aside from the above, little up-to-date information is available in air-drying of lima beans, especially fresh or frozen green limas. Consultation with the California Lima Bean Commission, the USDA, and local bean processors provided the following information on the major types of California-grown lima beans and their characteristics.

Type and Variety	Characteristics
Thorogreen	Thin-seeded, small-sized (baby), most important frozen lima, color jade-green.
Fordhook	Thick-seeded, large-sized lima. Harvested green for freezing or as white matured dry beans (the dried type also referred to as butter beans).
Emerald Green	Also known as Baby-Fordhook. Thick-seeded, small-sized lima. Also commercially available as frozen beans.
Ventura	Available only as field-dried lima.

The selection of varieties used in this study was based on the above lima bean characteristics.

The objective of this investigation was to provide information on the relative effects of selected raw material and processing variables pertaining to the optimum conditions for air-drying of lima beans. The variables studies were variety, maturity (bean size), pretreatment effects, drying-air temperatures, drying-air velocities, and tray loadings. Frozen lima beans representing the selected test conditions were air-dried, packaged under inert atmosphere in hermetically sealed containers, stored six months at 100^{o}F, and sensory tested against a control sample stored at 0^{o}F.

No attempts were made in either study to develop and produce the best quality freeze-dried fruits or air-dried lima beans. Both studies were designed as a series of screening tests to identify the relative effects of the various selected raw material and process variables involved in freeze-drying of fruits and air-drying of lima beans.

MATERIALS AND METHODS

Freeze-Drying of Fruits

To reduce large number of variables in this investigation to a workable amount, preliminary screenings were made to select a suitable combination of raw material and processing variables for each type of fruit. This particular combination of variables was designated "control." To study the effect of individual factors, only one variable was introduced at a time to replace a comparable variable from the "control". The number of alternative variables introduced depended on the type of fruit. For each type of fruit, a control was stored at 100°F along with the variable runs.

Chemical and Physical Measurements of Fruits

Total soluble solids (°Brix), pH, titratable acidity, and moisture content were determined for each type of fruit used in the study (AOAC, 1970). Texture measurements were made using two modified Magnus and Taylor Fruit Pressure Testers, Models 10A and 30B, with a 5/16" tip. Results were reported as pounds of resistance. Measurements of these chemical and physical properties were used as a basis for judging the degree of fruit ripeness as well as for quality assurance and consistency.

Blanching of Fruits

Except for strawberries, all fruits were blanched before freezing. Proper blanching methods for pears, apricots, and peaches were developed or adapted. Adequacy of blanching for each fruit and particle size was determined using the USDA method (Tressler *et al.*, 1145-1147, Vol. 1, 1957).

Fruit Sources

All fruits used in this study were purchased from Sunset Produce Co. and Lee-Ray Tarantino Co., both of the South San Francisco Produce Terminal.

Fruit	Variety	Growing Area
Pears	D'Anjou	Hood River, Oregon
	Bosc	Hood River, Oregon
Strawberries	Shasta	Watsonville, California
	Tioga	Watsonville, California
Apricots	Royal	Winters, California
	Tilton	Sacramento area, California
Peaches	Rio Oso Gem	Fresno, California
	Fay Elberta	Fresno, California

Processing

Pears

Medium-sized (44 count/box) pears about 1/4 ripe were purchased and stored in their original cartons at room temperature until they reached the ripeness for processing. Whole pears were washed, hand-peeled, halved, cored, and cut into approximately 1/2" X 3/4" X 1/2" dices. (To study the effect of particle sizes, pear halves were used.) Diced pears were held in 0.5% ascorbic acid solution during preparation and blanched in that solution at 190°F for 3 min (8-1/2 min for pear halves). Blanched pear dices were cooled in tap water for 2 min and drained for 1 min before freezing. For each test run, 24 lb of pear dices (or halves) were prepared. Four lb of prepared pears were placed one layer deep on each of six 12" X 24" X 2" freeze-drying trays. (To study the effect of tray loading, 8 lb per tray for three trays were used). Each tray with prepared pears was individually frozen by a continuous spray of liquid nitrogen (LN_2) or, in the case of the freezing variable, a shelf freezer. Time required to completely freeze one tray with liquid nitrogen spray depended on particle sizes and tray loads (4 lb of dices: 10 min, 4 lb of halves: 15 min, and 8 lb dices: 20 min.) Frozen pears were freeze-dried under selected platen temperatures and chamber pressures. A list of experimental runs using different fruit and process variables is shown below.

Run No.	Variable Introduced
13	Maturity, full ripe
14	Low platen temperature, 100°F
15	Control[1]
16	Additive 1, calcium lactate[2]
17	High platen temperature, 160°F
18	Freezing method, -30° shelf freezing
19	Particle size, halves
20	Additive 2, 14 °Brix blanching solution
21	Variety 1, Bosc pears
23	High tray load, 8 lb per tray, 3 trays per run
27	Variety 2, Bartlett pears
28	High chamber pressure, 400-700 μ[3]
29	Special control for Run 28[3]
30	Frozen control[1]

[1]The variables selected for control and frozen control were: variety-D'Anjou; maturity--3/4 ripe; additive--none; freezing method--LN_2 spray; particle size--dices; tray load--4 lb per tray, 6 trays per run; platen temperature--, 130°F, chamber pressure--100 μ ± 50 μ. Run 15 was put into six months storage at 100°F, and Run 30 was kept frozen.

[2]Blanched pear dices were soaked at ambient temperature in 0.5% Calcium lactate for 20 min before freezing.

[3]Runs 28 and 29 were processed in a modified Stokes freeze-dryer.

Strawberries

Medium-sized (commercial size grading), ripe strawberries were purchased and processed the same day. Whole strawberries were washed, stemmed and inspected. Abnormally small or large berries were discarded before freezing. Twenty-four lb of strawberries were used per freeze-drying run. A list of experimental runs using different fruit and process variables is shown below.

Run No.	Variable Introduced
5 (& 5A)	Maturity, early season[1]
8 D	Control[2]
10	Low platen temperature, 100°F
11	Variety, Tioga
12	High platen temperature, 150°F
13	Freezing method, LN_2 spray
14	Particle size, halves
15	High tray load, 8 lb per tray per run
16	Pretreatment, scarification[3]
17	Additive, calcium lactate; soak 0.5% for 20 min at ambient temperature[2].
19	Frozen control
20	High chamber pressure, 400-700 μ[4]
21	Special control for Run 20[4]

[1] Since strawberries are picked and sold in the ripe stage, early season strawberries, which are lower in °Brix and firmer in texture, were used to demonstrate maturity difference.

[2] The variables selected for control and frozen control were: variety--Shasta; maturity--peak season, ripe; pretreatment--none; additive--none; freezing method--30°F shelf freezer; particle size--whole; tray loading--4 lb per tray, 6 trays per run; platen temperature--125°F; chamber pressure--100 μ ± 50 μ.

[3] Scarification was used to demonstrate the effects of pretreatment on rehydration rate. On a small piece of plywood, nine 1" long thin brads (.046" diameter) were mounted, evenly spaced with the sharp points up, in an area 1" square. Each strawberry was punctured four to six times on all sides depending on fruit size.

[4] Freeze-dried in the modified Stokes Freeze-Dryer.

Apricots

Large-sized apricots, commercial size grading, were purchased 1/4 ripe and held at room temperature (65° to 75°F) to reach the desired stage of ripeness. The apricots were then sorted, washed, halved (or sliced as in Run 7), pitted by hand, held in 0.5% ascorbic acid during preparation, and blanched 3-1/2 min in boiling water). Blanched apricots were cooled in tap water for 2 min, drained, frozen 4 lb per tray (or 8 lb

per tray as in Run 10) in -30°F shelf freezer (or with LN_2 spray as in Run 9), and freeze-dried under the selected conditions. Twenty-four lb of prepared halves or slices were used per freeze-drying run. A list of experimental runs using different fruit and process variables is shown below.

Run No.	Variable Introduced
1	Maturity, early season 1/4 ripe
4	Control[1]
5	Frozen control[1]
6	Variety, Tilton
7	Particle size, slices
8	Low platen temperature, 100°F
9	Freezing method, LN_2 spray
10	High tray load, 8 lb per tray, 3 trays per run
11	High platen temperature, 160°F
12	Additive 1, 1.0% calcium lactate in blanching water
13	Additive 2, 20 °Brix blanching solution
15	High chamber pressure, 400-700 μ[2]
16	Special control for Run 15[2]

[1]The variables selected for the control and frozen control were: variety--Royal; maturity--3/4-full ripe; particle size--halves; tray load--4 lb per tray, 6 trays per run; additive--none; freezing method-- -30°F shelf freezer; platen temperature--130°F; chamber pressure--100 μ ± 50 μ.

[2]Runs 15 and 16 were made using the modified Stokes Freeze-Dryer.

Peaches

Medium-sized peaches (56 counts per crate) were purchased and stored at ambient temperature (70-80°) until they reached the desired degree of ripeness. The fruits were peeled, halved, pitted, sliced into 1/2" to 3/4" bottom width wedges (or kept as halves as in Run 13), and held in 0.5% ascorbic acid solution during preparation. Two peeling methods were developed for this study which are described below.

Lye-Peel--Although applicable to all stages of ripeness, this method was used only for green and firm peaches when necessary. Halved peaches were dipped in a 1.0% NaOH solution at 195°F for 1/2 min, rinsed in cold tap water, and peeled by hand rubbing. The excess lye was neutralized in a 0.5% citric acid solution at ambient temperature for about 2 min. This procedure is a slight modification of commercial practice.

Hot-Water Peel--When peaches passed the 1/2-ripe stage and started to soften on finger pressure, a simple hot water peeling method was used. Whole peaches were immersed in a 195°F water bath for 30 sec and cooled immediately in cold tap water; peels were easily removed after such treatment. This method was used to process all peach runs except Run 7.

Peach slices were blanched in 195 to 200°F water for 3 min (halves were blanched 8-1/2 min). Twenty-four lb of blanched slices (or halves) were frozen and freeze-dried per run. A list of experimental runs using different fruit and process variables is shown below.

Run No.	Variable Introduced
3	Variety, Fay Elberta
7	Maturity, 1/4-ripe
8	Control[1]
9	High platen temperature, 160°F
10	Frozen control[1]
11	Low platen temperature, 100°F
12	Maturity 2, full ripe
13	Particle size, halves
14	Freezing method, LN_2 spray
15	Tray load, 8 lb per tray, 3 trays per run
16	High chamber pressure, 400-700 μ[2]
17	Special control for Run 16[2]

Run No.	Variable Introduced
18	Additive 1, 1.0% calcium lactate blanching solution
19	Additive 2, 15 °Brix + 0.5% citric acid blanching solution

[1]The variables selected for the control and frozen control runs were: variety--Rio Oso Gem; maturity--3/4-ripe; particle size--slices; tray loading--4 lb per tray, 6 trays per run; additive--none; freezing method-- -30°F shelf freezer; platen temperature--130°F; chamber pressure--100 μ ± 50 μ.

[2]Runs 16 and 17 were made using the modified Stokes Freezer-Dryer.

Freeze-Drying

Two pilot plant model freeze-dryers were used in this study. A Del-Vac freeze-dryer was used for most of the freeze-drying runs. A modified Stokes Freeze-Dryer with a positive chamber pressure control was used for those tests requiring high chamber pressure (400-700 μ). Since this involved an equipment variable in addition to the chamber pressure variable, a special control was made using the modified Stokes chamber.

For each drying operation, platen temperature was raised to the desired setting as soon as the chamber pressure reached 150 μ. This required between 30 min to 1 hr. Platen temperature was held constant throughout the drying cycle. No attempt was made to study the efficiency of freeze-drying. Platen temperature, product and tray temperatures, and condenser temperature (about -50°F) were all monitored by a 12-point thermocouple with recorder printouts. End-points were determined by temperature equilibration among thermocouple readings of product, freeze-drying trays, and platens. At the end of each freeze-drying run, chamber vacuum was broken with nitrogen.

Packaging and Storage

To avoid oxidative effects, immediately after the vacuum was broken, dried samples were weighed and packaged under nitrogen in No. 10 cans. Cans were filled, evacuated to 29" Hg, and broken with nitrogen. This

process was repeated before cans were sealed. Except for the frozen storage samples, all packaged samples were stored for six-months at 100°F. Storage temperature was controlled thermostatically and monitored to 100°F ± 5°F throughout the six-month period.

Air-Drying of Lima Beans

Bean Sources

Commercially frozen California-grown Thorogreen, Fordhook, and Emerald Green Varieties of lima beans were purchased in bulk from Patterson Frozen Foods in Patterson, California, and Stokely Van Camp in Santa Clara, California. The frozen lima beans were held at 0°F until processed.

Dryer

A new tray dryer, suitable for air-drying of lima beans, was designed and built by SRI staff technicians. The dryer, made of wood, was capable of holding five drying trays per operation. The trays were made of 1/4" mesh stainless steel screen with a dimension of 24" X 24" X 4". Drying air was heated by passing it through a gas-fired heat exchanger. Air temperature was thermostatically controlled with an accuracy of ± 2°F. Air velocity was regulated by perforated screens and measured with a Biram anemometer.

Moisture Determination

Moisture contents (AOAC, 1970) were determined for all three varieties of lima beans before and after drying.

Peroxidase Test

A peroxidase test (Tressler et al., 1145-1147, Vol. 1, 1957) was performed on all frozen lima beans to check the adequacy of the commercial blanch, and on all dried lima beans after six months storage at 100°F to check any possible enzyme regeneration.

Air-Drying

Each experimental run was dried in the dehydrator previously described. Drying time varied depending on the predetermined variables and processing conditions. For each drying operation, only one variable or one processing condition was investigated, and only one drying tray was used. Drying temperature and bean temperature were monitored by thermocouples with recorder printouts as well as two bi-metal thermometers, one for incoming air and the other for outgoing air. Air velocity was checked by the Biram anemometer. Weight reduction of beans was recorded at 1/2- to 1-hr intervals throughout the drying cycle. The drying operation was considered complete when no weight change was detected over a 1-hr period.

Processing

After a number of preliminary trial runs using different combinations of variables and processing conditions, a set of nine variables was selected for the control:

(1) Thorogreen variety

(2) Blanched and frozen

(3) No thawing prior to drying

(4) 12 lb per tray load per run

(5) No pretreatment

(6) No additive

(7) No size-sorting

(8) 140°F drying temperature

(9) 120' per min air velocity

To study the relative effects of each individual variable, only one variable was introduced at a time to replace a comparable variable from the control.

The following list summarizes the different raw material and processing variables investigated in production runs of lima beans.

Run No.	Variable Introduced
9	Fresh lima (blanched)
12	Control[1]
13	High air temperature, 180°F
14	Frozen control[1]
15	Varietal difference 1, Emerald Green
16	Low air temperature, 100°F
17	Low Air Velocity, 30'/min
18	Varietal difference 2, Fordhook
19	Bean-size difference 1, small Thorogreen[2]
20	Bean-size difference 2, large Thorogreen[2]
21	High tray load, 24 lb
22	Samples thawed before drying
23	Samples thawed and reblanched before drying[3]
24	Additive, PO_4-soaked[4]

[1] Process conditions used for control and frozen control are listed on the previous page.

[2] Frozen Thorogreen lima beans were sorted with a 2'5" X 1'7" screen with 0.395" openings at 2 mesh and 12 gauge. This screen was selected because it retained 60% of the frozen beans and allow 40% to fall through. Those that fell through the screen were used in Run 19, and those retained were used in Run 20.

[3] To study the possibility of enzyme regeneration during accelerated storage, this run was made using reblanched samples. Frozen limas were thawed to 50°F and reblanched for 3-1/2 min in 190 to 200°F water. Reblanched samples were cooled in tap water for 1 min and drained for 1 min before drying. Adequacy for blanching before reblanching was tested and found to be satisfactory.

[4] Frozen lima beans were allowed to thaw to 50°F and soaked in a 4-gal. phosphate solution consisting of 0.35% anhydrous trisodium phosphate, 0.15% phosphoric acid, and 1.0% sodium chloride with pH adjusted to 9.6 (by adding additional trisodium phosphate if necessary). After 2 hr of soaking at room temperature, the beans were drained for 2 min and air-dried.

Packaging and Storage

The air-dried beans were cooled to ambient temperature, weighed, and packaged under nitrogen in No. 10 cans. Cans were filled, evacuated to

29" Hg, and broken with nitrogen. This process was repeated before the cans were sealed. Except for frozen control samples, all packaged samples were stored for six months at 100°F. Storage temperature was controlled thermostatically and monitored to 100°F ± 5°F throughout the six-month period.

Rehydration

At the end of the six-month period, canned samples were withdrawn from 100°F storage and held at 0°F until sensory-tested. Rehydration times for each control and variable were reasured at room temperature before and after storage.

Sensory Testing Procedure

Testing Facility and Materials

The sensory evaluation facility is located at the end of a quiet corridor. The room is kept at 68 to 74°F by an independent air-conditioning system. At opposite ends of the room are two smaller rooms, each containing four taste booths. These rooms have their own entrances and each booth has a pass-through into the preparation room. The individually partitioned booths and counters are a gloss white; there are individual lights and small sinks with running water in each booth. These smaller rooms are cooled by circulating air from the preparation room; the air is vented to the outside.

For this study, we used ramekins obtained from a restaurant supply house. They are 3" in diameter and 1-1/2" high, with a capacity of 80 ml. The outside is maroon glaze, the inside white glaze. They are coded with three-digit numbers on the outside for sample identification. These and the water glasses are washed in a Hobart dishwasher using Finish® dishwashing compound (a satisfactory procedure used previously).

Panel Selection and Training

Nine volunteers (five women and four men) with previous sensory testing experience were selected for training from among Institute staff.

Three training sessions were held per product. During the first, a round-table session, panelists were familiarized with the test procedure and questionnaire; they were then familiarized with a variety of samples used to illustrate varying degrees of positive and negative product characteristics. Panel discussion was allowed following presentation of each training sample, and general agreement was reached on product scoring. The second and third training sessions were similar to the first except that they were conducted in the Institute taste booths, and no discussion was allowed. On completion of training, a final panel of eight (three men and five women) was selected.

Sample Handling and Preparation

At the end of the six-month accelerated storage period, samples were allowed to cool gradually at room temperature before being transferred to the freezer. All samples were kept under frozen storage (0°F) until ready for testing.

An adequate rehydration method was devised for each freeze-dried fruit and air dried vegetable. Sample preparation varied depending on the individual product being tested.

Testing Procedure

Judges tested twice daily, in the morning at either 11:00 or 11:30 and in the afternoon at 2:30 or 3:00, for one week. Missed sessions were made up 15 min before or after a scheduled test session. Each judge evaluated half the samples in the morning session and half in the afternoon session, so that all test samples were evaluated once each day by each judge.

When each judge arrived to test, he or she sat in a taste booth and was given a score sheet together with a spoon and one tablespoon of product in a coded ramekin. On completion of the score sheet, the subject returned it and the ramekin to the experimenter and waited for the second sample, etc.

Judges were allowed as much time as necessary to evaluate each sample and complete each score sheet.

Distilled water was used to rinse between samples, and judges were permitted to drink this.

Experimental Design

The testing sequence for the complete experiment was prepared in advance. Each of the samples was tested five times by each subject, yielding 40 responses for each attribute. The order of presentation was varied so that each sample was tested as equal a number of times in each position as was possible. Forty different orders were used, and each subject was randomly assigned five different orders.

Score Sheet

The score sheet used in this testing, shown in Appendix A, may be described as a series of Quality Rating Scales. The subject places a mark in the appropriate box representing his (or her) judgment regarding the product's quality on the specific attribute being evaluated.

Data Analysis

For the purpose of computation, the values 1-9 were assigned to the successive scale categories beginning at Extremely Poor. A computer program was prepared to perform analyses of variance on the data collected. Computer output included a mean scores for each sample on each attribute evaluated.

RESULTS AND DISCUSSION

Freeze-Drying of Fruits

Table 1 presents the chemical and texture measurements of the four types of fresh fruits used in this study.

Pears

Freeze-dried, blanched pears rehydrated completely within 1 min in distilled water at ambient temperature. Preliminary study indicated that unblanched pears shrank slightly after freeze-drying and did not rehydrate readily under these conditions. Six-months' storage at 100°F had no effect on rehydration as no difference was observed on rehydration rate before and after storage.

Results of sensory evaluation on freeze-dried pears are presented in Table 2. Among the different varieties tested, Bosc pears were rated best in overall quality. This might have been expected as the Bosc variety is regarded as a highly flavorful and premium-priced pear. In overall quality, there was no significant difference between the control frozen with LN_2 and -30°F shelf freezing, 3/4-ripe and full-ripe pears, pear dices and halves, or 4 and 8 lb per load. Blanching with 14 °Brix solution improved the color and aroma but had no significant effect on overall quality. Calcium lactate-treated samples stored at 100°F for six months did not show improvement in texture and were rated low in other quality attributes.

Among the three platen temperatures tested, 100°F was rated higher than 130°F and 160°F in overall quality. Samples freeze-dried at 100°F were significantly better than those freeze-dried at 160°F, even though neither were significantly different from the control samples freeze-dried at 130°F. Between the two samples freeze-dried at different chamber pressures, the control at 100 μ ± 50 μ was significantly better

Table 1

CHEMICAL AND TEXTURE MEASUREMENTS

Fruit	Pears			Strawberries			Apricots			Peaches			
Variety	D'Anjou		Bosc	Shasta		Tioga	Royal		Tilton	Rio Oso Gem			Fay Elberta
Maturity	3/4 ripe	full ripe	3/4 ripe	early season	peak season	peak season	1/4 ripe	3/4-full ripe	3/4-full ripe	1/4 ripe	3/4 ripe	full ripe	3/4 ripe
pH, pure	4.40	4.18	4.70	3.55	3.60	3.54	3.25	3.45	3.38	3.75	3.64	3.66	3.68
^{o}Brix	14.1	14.1	14.4	7.1	9.0	8.5	11.0	14.9	11.4	9.9	11.0	10.9	12.3
Titratable acidity, %	.49	.49	.28	---	.62	---	---	.80	---	.59	.59	.59	.55
H_2O, %	84.0	---	87.7	---	89.3	88.0	---	86.0	87.5	---	88.0	---	89.7
Texture value *	4.5	4.4	4.2	---	1.6	3.7	11.9	6.0	8.1	18.1	7.5	4.1	3.8

* Magnus and Taylor Fruit Pressure Tester.

Table 2

PANEL RATINGS ON QUALITY ATTRIBUTES OF FREEZE-DRIED PEARS

Variable	Sample No.	Appearance Sample No.	Appearance Ranked Mean Value	Color Sample No.	Color Ranked Mean Value	Aroma Sample No.	Aroma Ranked Mean Value	Texture Sample No.	Texture Ranked Mean Value	Flavor Sample No.	Flavor Ranked Mean Value	Aftertaste Sample No.	Aftertaste Ranked Mean Value	Overall Sample No.	Overall Ranked Mean Value
Bosc Variety	1	1	6.25	1	6.67	3	5.12	1	5.70	1	5.70	7	5.35	1	5.45
14 Brix Blanching	2	2	†5.12	5	5.72	2	4.87	7	5.40	7	5.40	1	5.30	7	5.05
-30°F Shelf-Freezing	3	3	4.90	2	5.12	8	4.85	6	5.10	2	5.20	2	5.27	2	5.00
Calcium Lactate	4	4	4.57	4	4.95	5	4.70	5	4.82	5	4.92	5	4.95	6	4.62
Full Ripe	5	5	4.52	3	4.52	7	4.67	9	4.75	10	4.87	10	4.90	5	4.50
Control*	6	6	4.35	6	4.22	10	4.60	2	4.65	6	4.75	9	4.82	9	4.40
100°F Platen (low)	7	7	4.05	7	4.15	1	4.57	3	4.55	9	4.67	6	4.65	3	4.37
160°F Platen (high)	8	8	3.97	8	3.70	6	4.50	10	4.32	8	4.52	8	4.65	8	4.27
8 lb Tray Load	9	9	3.40	9	3.15	4	4.42	8	4.10	3	4.50	3	4.62	10	4.17
Halves (particle size)	10	10	2.72	10	2.82	9	4.42	4	3.67	4	4.00	4	4.27	4	3.95
Control for High Chamber Pressure‡	11	11	6.60	11	6.43	11	5.97	11	6.10	11	6.20	11	6.17	11	6.30
High Chamber Pressure 400-700 µ‡	12	12	4.53	12	5.00	12	5.67	12	4.33	12	5.13	12	5.77	12	4.90
Frozen Control‡	13	13	7.77	13	7.83	13	6.17	13	6.90	13	6.10	13	6.67	13	6.73
Bartlett Variety‡	14	14	4.27	14	2.80	14	5.07	14	6.37	14	3.96	14	4.67	14	4.40

* Control sample: 3/4 ripe, D'Anjou variety, dices, 4 lb/tray load, no additive, LN_2 spray freezing, and 130°F maximum product temperature.

† Duncan's multiple range test, 5% level.

‡ Samples 11, 12, 13, and 14 were tested at a different time from sample 1 through 10.

in all quality attributes except aroma and aftertaste than the high chamber pressure samples at 400 to 700 μ. Fruit dried at high chamber pressure shriveled slightly, and did not regain their turgid appearance after rehydration.

Frozen control samples, tested at a different time from the stored control, received better than fair ratings in all seven quality attributes. Bartlett variety pears, also processed and tested at a different time from the stored control because of seasonal availability, were rated better than fair for texture but below fair for overall quality.

Strawberries

When freeze-dried strawberries were rehydrated in ambient temperature distilled water, a bluish color and grassy flavor started to develop in 20 to 25 min, indicating enzymatic oxidation. This was expected as the fresh strawberries were not blanched before freezing. Since each complete taste panel session required between 45 and 60 min, a rehydration medium using 3% sucrose solution was developed and found to be effective for up to 1 hr in retarding this adverse change in quality. A dilute solution of citric or ascorbic acid alone or in combination with sucrose was also effective.

Except for experimental runs 5, 5A, and 11, freeze-dried strawberries rehydrated well in ambient temperature water or in the 3% sucrose solution in 3 min or less. Little difference was observed before and after the six-months' storage at 100°F. Copson (1962) noted that freeze-dried strawberries rehydrated almost instantly in cold water. This was found to be only partially true in this study, depending on varietal, seasonal, and pretreatment differences. Tioga variety, a distant second in commercial importance to the popular Shasta did not rehydrate as well as the Shasta variety. Dried spots occasionally remained even after rehydrating the freeze-dried berries for 3 min, although they eventually rehydrated after the berries were removed from the rehydrating medium. Early season strawberries with lower than

8 ^{o}Brix and higher fiber content proved unsuitable for freeze-drying (De Alcuaz, 1971). These strawberries tended to float and did not take up water when placed in rehydration medium.

One interesting discovery with respect to the rehydration rate was the effect of scarification (Run 16). This prefreezing treatment was found to reduce rehydration time to less than 2 min compared with 3 min for unscarified fruits. Scarification had no adverse effect on fruit appearance before or after rehydration.

In the sensory evaluation of strawberries, fresh frozen strawberries purchased through local retail outlets were used for comparison with the freeze-dried samples. Results of the evaluation are presented in Table 3. Store-bought frozen strawberries, thawed overnight in a refrigerator, placed in the 3% sucrose solution for 5 min, and served at room temperature (72^{o}F) were rated superior in color, appearance, and aroma, but low in flavor, aftertaste, and overall quality compared with the freeze-dried counterpart. Panel ratings showed that 6-months' storage at 100^{o}F had an adverse effect on the sensory quality of rehydrated strawberries. Except in texture, the frozen control samples (Run 19) were rated significantly higher than the control samples stored at 100^{o}F for the same 6-months' period. Copson (1962) pointed out that storage at an elevated temperature might cause browning in freeze-dried strawberries. This phenomenon was observed in a few samples after 6 months of storage at 100^{o}F.

Calcium lactate-soaked samples showed no significant texture improvement over the control although the former was rated higher in overall quality. In general, texture ratings on all samples were low. Fast-freezing with LN_2 spray showed no advantage in texture over conventional shelf-freezing and caused occasional cracking and color bleaching of the fresh strawberries. Strawberry halves (Run 14) were rated significantly lower in appearance and color than whole strawberries. Fruit dried at 8 lb per freeze-drying tray compared favorably with the control at 4 lb per tray in overall quality.

Among the three platen temperatures studied, strawberries freeze-dried at 150^{o}F were rated better than the control at 125^{o}F, which in turn was better than the strawberries freeze-dried at 100^{o}F. This was

Table 3

PANEL RATINGS ON QUALITY ATTRIBUTES OF FREEZE-DRIED STRAWBERRIES

Variable	Sample No.	Appearance Sample No.	Appearance Ranked Mean Value	Color Sample No.	Color Ranked Mean Value	Aroma Sample No.	Aroma Ranked Mean Value	Texture Sample No.	Texture Ranked Mean Value	Flavor Sample No.	Flavor Ranked Mean Value	Aftertaste Sample No.	Aftertaste Ranked Mean Value	Overall Sample No.	Overall Ranked Mean Value
Frozen Store-bought	1	1	†6.12	2	6.30	2	7.50	2	4.82	2	6.92	2	6.62	2	6.72
Frozen Control	2	2	6.05	1	6.20	1	5.67	5	4.32	5	4.80	5	4.72	5	4.52
Tioga Variety	3	3	5.87	3	5.77	7	5.32	7	4.02	9	3.92	9	4.10	9	4.00
Control*	4	4	5.04	5	5.22	5	5.25	1	3.62	7	3.85	7	3.77	7	3.95
Pretreatment (Scarification)	5	5	4.92	4	5.17	3	5.07	9	3.55	8	3.22	8	3.37	8	3.57
Fast Freezing, Liquid N_2	6	6	4.85	6	4.95	9	5.02	3	3.52	4	3.05	11	3.07	10	3.35
High Tray Load (8 lb)	7	7	4.55	7	4.72	8	4.82	8	3.42	3	3.00	4	3.05	4	3.22
High Platen (150°F)	8	8	4.30	9	4.52	6	4.57	4	3.25	6	2.92	3	3.02	3	3.15
Additive (Calcium lactate)	9	9	4.30	8	4.35	4	4.47	10	3.02	10	2.65	6	3.00	6	3.07
Early Season	10	10	3.52	11	3.75	11	4.25	6	2.82	12	2.60	12	2.85	11	2.70
Particle Size (halves)	11	11	3.45	10	3.45	12	4.02	11	2.82	11	2.60	10	2.77	12	2.57
Low Platen (100°F)	12	12	2.42	12	2.57	10	3.70	12	2.57	1	1.47	1	1.52	1	1.65
Control for High Chamber Pressure‡	13	13	5.03	14	5.72	13	5.88	14	4.40	13	4.61	13	4.64	13	4.57
High Chamber Pressure (400-700 µ)	14	14	4.91	13	5.31	14	5.52	13	4.07	14	4.28	14	4.05	14	4.10

* Control sample: full ripe, Shasta variety, no pretreatment, no additive, whole strawberries, 4 lb tray load, -30°F shelf-freezing, and 125°F maximum product temperature.

† Duncan's multiple range test, 5% level.

‡ Sample 13 and 14 were tested at a different time from samples 1 through 12.

surprising as the maximum product temperature for freeze-drying of strawberries was considered to be 140°F (Hirshberg, 1971 and Strasser, 1971). In an attempt to study the effect of chamber pressure, it was found that at 125°F platen temperature, freeze-drying strawberries under 100 $\mu \pm 50\ \mu$ chamber pressure did not differ significantly from that between 400 to 700 μ in the final quality of the dried fruit after six-months' storage at 100°F. It should be emphasized that the adverse effect of high temperature storage was so dominant in the case of freeze-dried strawberries that the relative effects of most other process and raw material variables were overwhelmed.

Apricots

Freeze-dried apricot halves rehydrated in distilled water at ambient temperature in 3 to 3-1/2 min, and apricot slices in less than 2 min. Rehydration was considered complete when no dry spots remained in the flesh, even though the skin around the stem-end occasionally remained dry. Little difference was observed in the rehydration rate before and after six-months' storage at 100°F.

Results of sensory evaluation on freeze-dried apricots are presented in Table 4. The control stored at 100°F for six months was rated highest in flavor, aftertaste, overall quality, and was significantly better in the latter two quality attributes than the frozen control. No significant differences were observed in color, aroma, texture, and flavor between the stored and frozen controls. High tray loading (8 lb per tray) and 1/4-ripe apricots were both rated as inferior factors. In all seven quality attributes, LN_2 spray-frozen apricots were rated significantly lower than the control samples frozen by conventional shelf-freezer. Direct LN_2 spray altered the normal appearance of apricot halves by causing color bleaching and occasional cracking. It was assumed that with smaller fruit particle size, improved spraying equipment, and adequate precooling, these difficulties could be eliminated. Blanching apricots in 1% calcium lactate in place of water resulted in better texture for rehydrated apricot halves, but such treatment impaired other sensory qualities.

Table 4

PANEL RATINGS ON QUALITY ATTRIBUTES OF FREEZE-DRIED APRICOTS

Variable	Sample No.	Appearance: Sample No.	Appearance: Ranked Mean Value	Color: Sample No.	Color: Ranked Mean Value	Aroma: Sample No.	Aroma: Ranked Mean Value	Texture: Sample No.	Texture: Ranked Mean Value	Flavor: Sample No.	Flavor: Ranked Mean Value	Aftertaste: Sample No.	Aftertaste: Ranked Mean Value	Overall: Sample No.	Overall: Ranked Mean Value
Tilton Variety	1	1	+ 7.17	2	6.97	4	5.82	3	5.95	7	5.95	7	5.72	7	5.52
Frozen Control	2	2	6.67	1	6.90	7	5.75	1	5.67	4	5.65	5	5.02	4	5.52
Particle Size, slices	3	3	6.27	7	6.72	2	5.47	5	5.50	5	5.35	3	4.75	5	5.32
Low Platen (100°F)	4	4	6.27	5	6.47	3	5.45	4	5.02	8	5.05	2	4.70	3	5.17
High Platen (160°F)	5	5	6.25	4	6.45	5	5.05	8	4.82	2	5.02	4	4.57	8	4.95
Additive II, Sucrose	6	6	5.80	3	6.25	8	4.97	2	4.12	3	5.00	8	4.57	2	4.75
Control*	7	7	5.72	6	6.05	9	4.90	7	3.97	10	3.95	6	3.62	1	3.92
Additive I, Calcium Lactate	8	8	5.65	8	5.82	6	4.90	10	3.97	6	3.70	1	3.60	6	3.67
Early Season, 1/4 Ripe	9	9	4.65	9	4.10	1	4.85	9	3.70	1	3.62	10	3.55	10	3.10
High Tray Load (8 lb)	10	10	3.65	11	2.75	10	3.85	6	2.87	9	3.05	11	3.22	9	2.97
Fast Freezing, Liquid N_2	11	11	2.20	10	1.67	11	3.77	11	1.45	11	2.50	9	2.97	11	2.20
High Chamber Pressure, 400-700 µ ‡	12	12	6.23	12	6.67	12	5.30	13	4.10	12	6.00	12	5.77	12	4.73
Control for High Chamber Pressure ‡	13	13	5.20	13	4.80	13	4.30	12	3.97	13	3.80	13	3.73	13	3.50

* Control sample: 3/4 ripe, Royal variety, halves, 4 lb/tray load, no additive, -30°F shelf-freezing, and 130°F maximum product temperature.

\+ Duncan's multiple range test, 5% level.

‡ Samples 12 and 13 were tested at a different time from samples 1 through 11.

Blanching apricots with 20 ^{o}Brix solution in place of water showed no advantage in flavor after rehydration. Slices, although an unlikely configuration for processed apricots, were rated highest in texture among all the variables and were significantly better than the stored control using apricot halves. This texture improvement might be attributed to the shorter blanching time required for apricot slices and the faster rehydration rate.

In comparing varietal difference, freeze-dried Tilton apricots were rated significantly better in texture and appearance than the Royal apricots used in the control, but received low ratings for overall quality because of lack of flavor. As a fresh fruit, Tilton apricots are firmer in texture (see Table 1) with smoother skin and less fuzz than the popular Royal variety, but are a distant second in commercial importance, primarily because of their lack of flavor (Andrigetto, 1971).

Apricots freeze-dried at 160^{o}F platen temperature received a lower rating in aroma than the 100^{o}F and 130^{o}F samples, but compared with the two lower platen temperature samples in overall quality. Apricots freeze-dried at 400 to 700 μ chamber pressure received significantly higher panel ratings in all sensory qualities except texture than those freeze-dried at 100 μ ± 50 μ.

Peaches

Freeze-dried peaches rehydrated in ambient temperature distilled water in 1-1/2 to 3-1/2 min, depending on processing parameters. Full-ripe peaches rehydrated well within 1-1/2 min, while early season, 1/4-ripe peaches required up to 3-1/2 min. Dry spots were occasionally observed in the 1/4-ripe peaches after 3-1/2 min. No significant difference was observed in the rehydration rate before and after storage at 100^{o}F. Some variation in the rehydration rate within the same processing condition was observed, which could be attributed to inherent differences among slices of the same peach as well as among peaches of the same degree of ripeness.

Results of sensory evaluation of freeze-dried and rehydrated peaches are presented in Table 5. Panel ratings of all seven quality attributes were generally low. Six-months' storage at $100^{o}F$ caused some degree of color darkening in the freeze-dried peaches. The frozen control sample was rated significantly higher for color, appearance, and texture than the stored control. However, no significant difference was observed in flavor, aroma, aftertaste, and overall quality between the two.

In varietal difference, Fay Elberta peaches, although softer in texture than Rio Oso Gem of comparable ripeness, had comparable texture and significantly better flavor than Rio Oso Gem when freeze-dried. The California Freestone Peach Association's "Varietal Characteristics Chart"* rates Fay Elberta (the leading Freestone peach) "good to poor" for freezing while Rio Oso Gem is rated "good".

Freezing with LN_2 spray showed no improvement in the texture of rehydrated peaches over conventional shelf-freezing. As with the freeze-dried apricots, LN_2-frozen peaches received significantly lower ratings in color and appearance because of color bleaching and occasional cracking.

In overall quality, there was no significant difference from the stored control for such variables as additives (sugar and acid blanch and calcium lactate blanch), variety (Fay Elberta), particle size (halves), high platen temperature ($160^{o}F$) and high chamber pressure (400 to 700 μ) during freeze-drying.

Differences in maturity showed 1/4-ripe peaches to be unsuitable for freeze-drying, not only for their lack of color, aroma, and flavor but also because their sole advantage of having a firm texture was lost when they often did not rehydrate completely. Full-ripe Rio Oso Gem peaches received the highest score in flavor and overall quality and were significantly better than the control with 3/4 ripe peaches of the same variety. As fresh fruits, full-ripe and 3/4-ripe Rio Oso Gem had nearly

* Available through USDA.

Table 5

PANEL RATINGS ON QUALITY ATTRIBUTES OF FREEZE-DRIED PEACHES

Variable	Sample No.	Appearance		Color		Aroma		Texture		Flavor		Aftertaste		Overall	
		Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value
Frozen Control	1	1	6.62 †	1	7.17	4	5.37	5	5.15	8	5.57	8	5.50	4	5.00
High Platen Temperature	2	2	5.40	2	5.70	6	5.37	1	4.85	4	5.50	4	5.50	8	5.00
Control*	3	3	5.37	3	3.32	7	5.37	6	4.42	5	4.82	10	5.00	5	4.85
Low Platen Temperature	4	4	5.05	12	5.00	9	5.17	8	4.42	10	4.80	5	4.87	10	4.25
High Tray Load (8 lb)	5	5	5.05	8	5.00	5	5.15	4	4.40	9	4.62	9	4.72	7	4.10
Particle Size (halves)	6	6	5.02	4	4.90	11	5.12	2	4.35	13	4.57	13	4.55	9	4.05
Sugar-Acid Blanch	7	7	4.85	6	4.77	12	5.10	9	4.20	7	4.22	3	4.37	6	4.02
Full Ripeness	8	8	4.70	7	4.77	13	5.00	7	4.20	12	4.00	7	4.30	13	3.97
Calcium Lactate	9	9	4.42	5	4.70	8	4.97	12	3.87	6	3.90	6	4.27	2	3.90
Fay Elberta Variety	10	10	4.25	14	4.50	3	4.92	3	3.77	2	3.85	14	4.17	1	3.87
LN_2	11	11	4.07	11	4.37	1	4.80	11	3.52	3	3.85	12	4.15	3	3.82
High Chamber Pressure 400-700μ	12	12	4.05	13	4.12	10	4.60	13	3.45	14	3.65	2	4.05	12	3.77
Control For High Chamber Pressure	13	13	3.92	10	4.10	14	4.52	10	3.35	11	3.60	1	3.82	11	3.45
Early Season Rio Oso Gem	14	14	3.67	9	3.65	2	4.52	14	2.30	1	3.45	11	3.72	14	3.00

* Control sample: 3/4 ripe, Rio Oso Gem, slices, no additive, 4 lb tray load, -30°F shelf-freezing, and 130°F maximum product temperature.

† Duncan's multiple range test, 5% level.

identical Brix and pH values, with the latter having a higher texture value at 7.5 compared with 4.1 for the full-ripe fruits (see Table 1). The 3/4-ripe peaches were selected on the basis of this texture advantage but as the panel results indicated, the full-ripe fruits when rehydrated not only had a better flavor but a better texture as well.

Freeze-drying peaches at 100°F platen temperature resulted in significantly better flavor and overall quality than the controls at 130°F. This was somewhat unexpected as 130°F was found to be adequate for apricots, and freeze-drying apricots at 100°F had no advantage in final quality over 130°F.

<u>Observations</u>

Based on the experimental results of this investigation, the following observations could be made in regard to freeze-drying of pears, strawberries, apricots, and peaches.

- The selection of suitable raw material appeared to be the most critical factor. Fruit variety and maturity are most crucial in determining the final quality of the four freeze-dried fruits.
- Except for strawberries, blanching was found to be necessary to ensure good appearance and proper rehydration as well as enzyme inactivation in the freeze-drying of pears, apricots, and peaches.
- No chemical additives used in this investigation were found to be effective in improving either texture or flavor.
- Fruit particle size proved to be an important variable as it affected blanching, freezing, freeze-drying, and rehydration requirements.
- Conventional shelf-freezing appeared to be more suitable than LN spray.

<u>Recommended Product Temperature Range During Freeze-Drying</u>

Pears	100°F - 130°F
Strawberries	125°F - 150°F
Apricots	100°F - 130°F
Peaches	100°F - 130°F

Recommended Chamber Pressure Range During Freeze-Drying

Pears	100 μ ± 50 μ
Strawberries	up to 700 μ
Apricots	up to 700 μ
Peaches	up to 700 μ

Lima Beans

Moisture Determination

Table 6 presents the moisture contents of the three types of lima beans used before and after air-drying.

Table 6

MOISTURE CONTENT OF LIMA BEANS

Run No.	Variety	Avg. % Moisture before Air-Drying, Frozen	Avg. % Moisture after Air-Drying
12	Thorogreen	68.0%	7.32%
15	Emerald Green	72.0	4.79
18	Fordhook	71.4	5.63

Peroxidase Test

The results of the peroxidase test on each experimental run of dried lima beans after six-months' storage at 100°F indicated negative enzyme activity.

Rehydration

Rehydration time at ambient temperature in distilled water for the freshly dried lima beans was around 70-85 min. Little change was observed under similar rehydration conditions after six-months' storage at 100°F. Rehydration was considered complete when no center dry-spot was left in the beans.

Preliminary Screening and Sensory Testing

Samples stored at 100°F for six-months deteriorated drastically in all organoleptic qualities. A preliminary screening was made to reject those dried beans with such poor quality that formal sensory evaluation was not necessary. Rejection was made when dried beans did not become edibly soft after 1-1/2 hr of cooking. Cooking was done by placing dried beans in large glass beakers with ample distilled water (ambient temperature) over hot plates. Beans in water were slowly brought to a boil and were cooked in boiling water up to 1-1/2 hr. This cooking procedure was adopted as it simulated that used for commercial field-dried lima beans. The following is a list of the samples that were rejected and those that were sensory tested.

Sensory Tested		Rejected	
Run No.	Variable	Run No.	Variable
9	Fresh lima, blanched	15	Emerald green variety
12	Control	16	Low Air temp., 100°F
13	High air temp., 180°F	17	Low air velocity, 30'/min.
14	Frozen control	18	Fordhook variety
21	High tray load 24 lb	19	Small size bean
24	PO_4 soaked	20	Large size bean
		22	Thawed sample
		23	Thawed and reblanched

During sensory testing of rehydrated lima beans, 10 to 16 cooked beans were used per serving along with about one teaspoon of juice. Serving temperature was 113 to 122°F. Results of sensory evaluation are presented in Table 7.

From the results of sensory evaluation, it was evident that six-months storage at 100°F significantly impaired all the seven quality attributes tested. Air-dried lima beans stored at 0°F during the six-month period (frozen control) were rated 6.80 and higher on the 9-point scale for all quality attributes and were significantly better in every quality attribute than the control sample stored at 100°F for the same period.

Table 7

PANEL RATINGS ON QUALITY ATTRIBUTES OF AIR-DRIED LIMA BEANS

			Appearance		Color		Aroma		Texture		Flavor		Aftertaste		Overall	
Run No.	Variable	Sample No.	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value	Sample No.	Ranked Mean Value
14	Frozen control*	1	1	6.90	1	7.48	1	7.18	1	6.80	1	7.45	1	7.30	1	7.33
12	Control*	2	2	6.28	2	6.38	2	5.83	2	5.68	2	5.95	2	6.05	2	5.98
13	High Air Temp.	3	3	†5.05	4	4.95	3	4.43	3	4.88	3	4.70	3	4.78	3	4.60
24	PO_4-Soak	4	4	5.05	3	4.78	4	4.38	4	4.83	4	4.25	4	4.33	4	4.28
8	Fresh Beans	5	5	4.65	5	4.03	5	4.10	6	3.15	6	3.40	6	3.95	6	3.25
21	High Tray Load	6	6	4.43	6	3.45	6	3.58	5	2.10	5	2.50	5	3.20	5	2.60

* Control and frozen control variables included: Thorogreen variety, blanched and frozen, no thawing prior to drying, 12 lb per tray load per run, no pretreatment, no additive, no size-sorting, 140°F drying temperature, 120' min air velocity.

† Duncan's multiple range test, 5% level.

The frozen control samples had a light jade-green color in the dry state, while the stored counterpart appeared less greenish with light brown mottled spots. This color difference became less obvious when the dried beans were rehydrated and cooked. No difference was observed in cooking time between the frozen control and the stored control. Among samples stored at 100°F for the six-months' period, the control sample was rated significantly higher than others tested. It received mean values of 5.68 or better for every quality attribute. The stored control samples required a significantly shorter cooking time of approximately 50 min, while others required between 70 to 90 min.

The thick-seeded varieties of lima beans (Fordhook and Emerald Green) were inferior to the Thorogreen variety as an air-dried product as their structure collapsed on drying. These lima beans also shriveled and had excessive mottling and skin-cracking. Most of the Emerald Green lima beans shrank to less than half their original thickness. The Thorogreen lima bean, which is a thin-seeded type, retained its shape and general appearance when dried. A certain degree of mottling, fish-mouthing, and skin-cracking were observed in all the production runs, however, these defects became barely noticeable when the beans were completely rehydrated. Dried beans from experimental runs 9, 22, 23, and 24 where beans were either fresh or thawed showed more mottling than other runs in which frozen beans were placed directly into the hot air stream without thawing. Brown et al. (1968) reported that mottling occurred in Great Northern and Small White beans regardless of drying conditions but that tumbling during the initial stages of drying tended to minimize mottling during air-drying of White Seed Coat limas. They concluded, after a series of tests using lima beans from different growing areas and different years of production, that "the quality of the raw bean is far more important to final product quality than the method of drying." Their finding seemed to agree with our observations that little difference in product quality was apparent within the same variety dried under various conditions before the six-months' storage at 100°F.

Quality differences among various runs increased after the accelerated storage. Sensory test results clearly indicated that next to bean variety, drying temperature and air velocity were the two most important variables. Drying at 140°F gave higher quality dried beans than drying at 180°F, which slightly scorched the beans. At 100°F, excessive dripping occurred during initial drying as the 100°F warm air gradually thawed the frozen beans before any appreciable evaporation took place. This simulated the drying of prethawed beans and resulted in lower quality products, Rockland et al. (1967) maintained that drying hydrated, quick-cooking beans at 140°F or below (at 30'/min or lower air velocity) resulted in better dried lima beans than drying at temperatures ranging from 150 to 170°F, which caused detectable burned flavors. In our test runs, drying frozen lima beans at 30'/min air velocity had the same undesirable thawing effect as drying at 100°F. Air velocity higher than 120'/min tended to fluidize the beans in our dryer, creating a different drying condition; therefore, no higher air velocity than 120'/min was used.

Drying rates as measured by bean weight reduction per unit time and total drying time as determined by constant bean weight at the end of the drying cycle did not differ greatly among various drying temperatures and air velocities. Figure 1 compares the drying rates and total drying time for the four drying conditions investigated.

Presoaking thawed lima beans in phosphate solution showed no improvement in rehydration and cooking time of the air-dried lima beans. The adverse effect of thawing the beans before soaking possibly masked any softening effect previously noted in using this particular phosphate solution (J. P. Nielsen, 1960).

High tray loading at 24 lb per tray produced lower quality dried beans than tray loading at 12 lb per tray. For the 2' X 2' X 4" tray, 12 lb per tray represented a 1" loading thickness. Even though very little difference in bean appearance and rehydration time was observed immediately after drying, significant differences in all seven quality attributes were detected by the sensory panel after six-months' storage at 100°F between the two tray loadings. This could be attributed to uneven drying in the high tray loading with a stack of 2" of frozen beans in the tray.

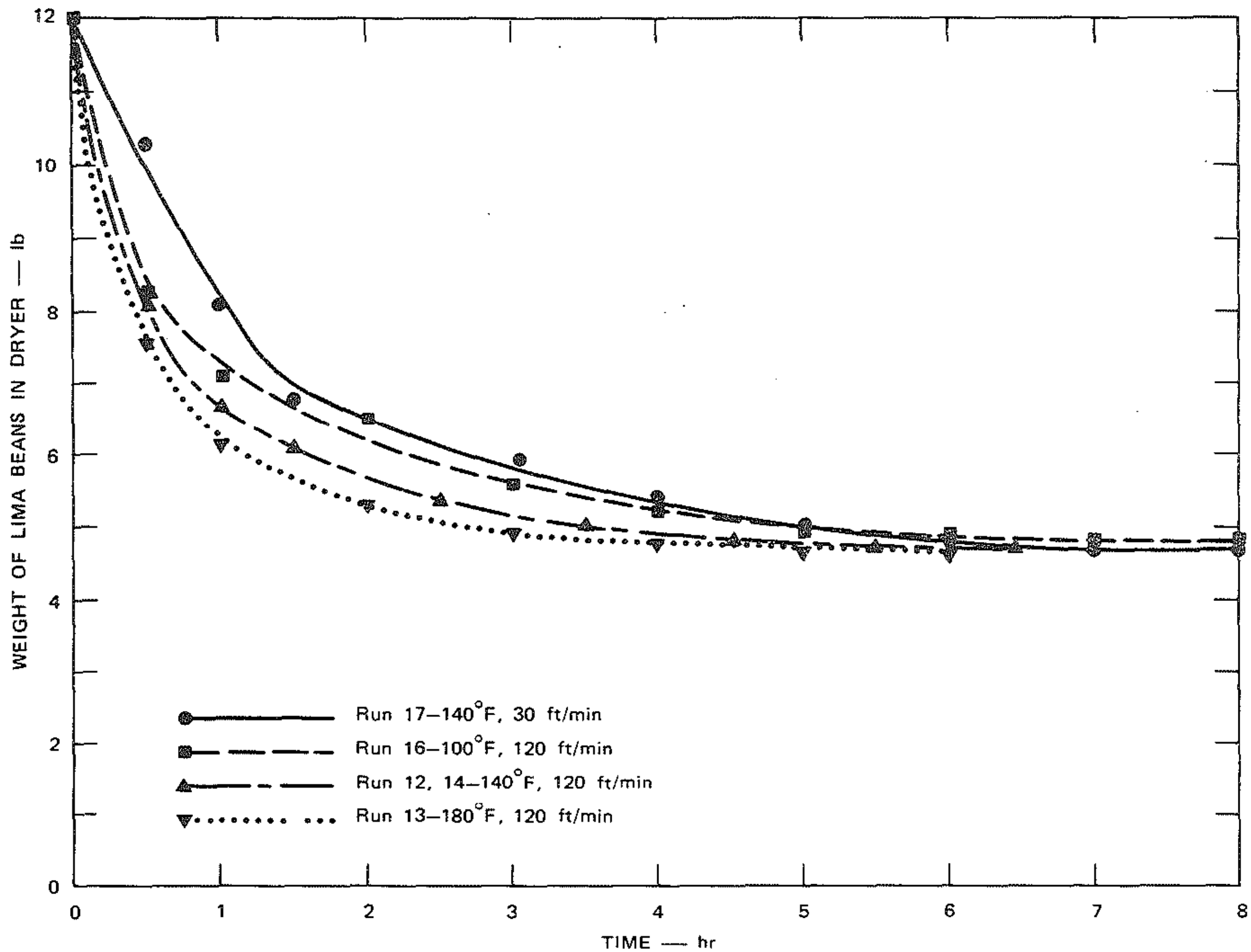

FIGURE 1 DRYING RATES AND TOTAL DRYING TIME IN AIR-DRYING OF LIMA BEANS AT FOUR DIFFERENT TEMPERATURES AND AIR VELOCITY SETTINGS

Larger-sized Thorogreen lima beans had a more uniform appearance with less mottling when dried than the smaller-sized beans. This observation was valid even after six-months' storage at $100^{\circ}F$. However, the overall appearance of the larger-size beans was less favorable than that of the unsorted control. This could have been caused by partial thawing during size sorting with the previously described wire screen. Some seed coat damage was also observed during screening of the frozen beans.

Observations

Based on results obtained in this investigation, we conclude that varietal selection is the most dominant factor in air-drying of lima beans using commercially available frozen beans as the starting material. Thin-seeded varieties such as Thorogreen resulted in far better quality dried beans than such thick-seeded varieties as Fordhook and Emerald Green. Frozen beans should not be thawed before drying. Predrying treatments such as reblanching and phosphate soaking were not feasible as thawing would be necessary before any such treatment. Without means of tumbling or rearranging the beans during drying, tray loading should not exceed 1" thickness to avoid uneven drying. Drying air temperature should be high enough to avoid slow thawing during initial drying yet not so high as to scorch the beans. A temperature of $140^{\circ}F$ proved adequate. Air velocity was not as critical as air temperature.

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Appendix

SCORE SHEET

Name ____________________ Date ____________________ Code ______________

Please, taste the sample and evaluate each of the following by checking the appropriate box (answer the questions in the order of their appearance). When you have finished the sample, return the dish and score sheet and wait for the next sample. If you have any questions or need more sample, ask the experimenter.

Thank you.

	Extremely Poor	Very Poor	Poor	Below Fair Above Poor	Fair	Below Good Above Fair	Good	Very Good	Excellent
Appearance									
Color									
Aroma									
Texture									
Flavor									
Aftertaste									
Overall									

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13. ABSTRACT

The relative effects of process and raw material variables on final product quality were determined for freeze dried strawberries, pears, peaches and apricots, and air-dried lima beans. Raw material variables studied were variety and maturity. Process variables included drying temperature, tray loading, additives and particle size. Variables involving freezing temperature, chamber pressure and air velocity were included as applicable. Following drying, samples were packed in a nitrogen atmosphere and placed in accelerated storage (100^{o}F) for 6 months.

Varietal selection, stage of maturity and particle size were significant factors affecting the quality of freeze dried fruits and air dried lima beans. Except for strawberries, blanching was found necessary to ensure good appearance and proper rehydration as well as enzyme inactivation in the freeze drying of pears, apricots and peaches. Chemical additives did not improve either texture or flavor of rehydrated products.

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